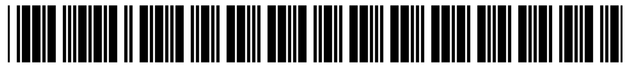
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(54) **PAD STRUCTURE FOR COPPER INTERCONNECTION AND ITS FORMATION**

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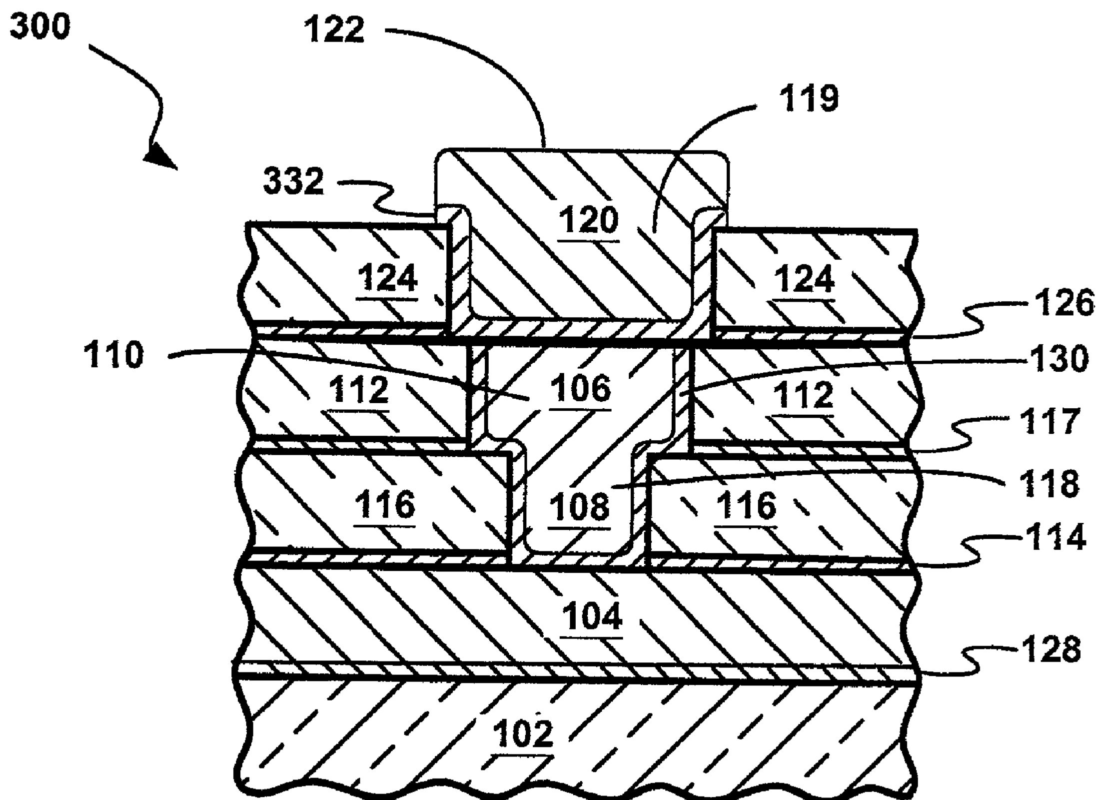
(57) **ABSTRACT**

A semiconductor device with high conductivity interconnection lines formed of high conductivity material, such as copper, is manufactured using tantalum nitride material as barrier material between an aluminum layer, such as the wire bonding layer, and the underlying high conductivity interconnection lines. The tantalum nitride material contains high nitrogen content.



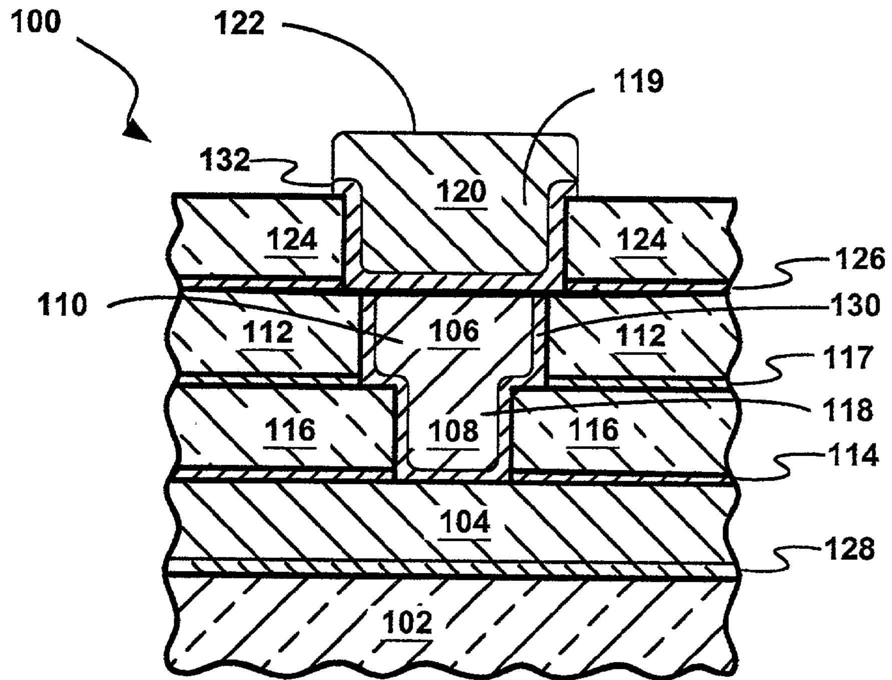


FIG. 1 (PRIOR ART)

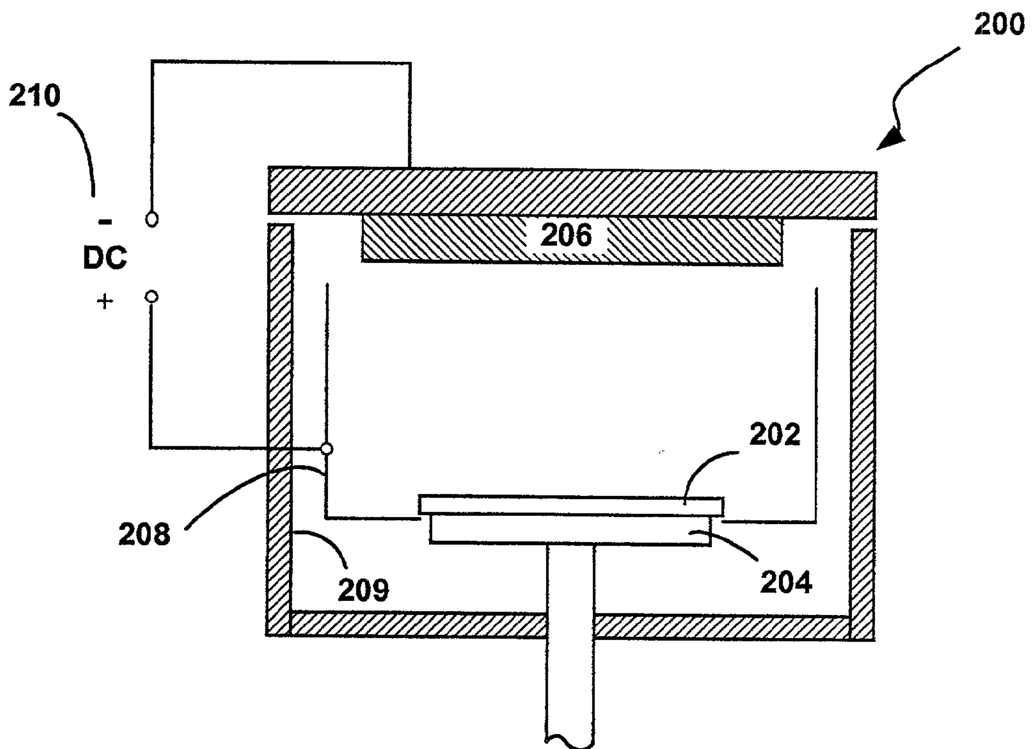


FIG. 2 (PRIOR ART)

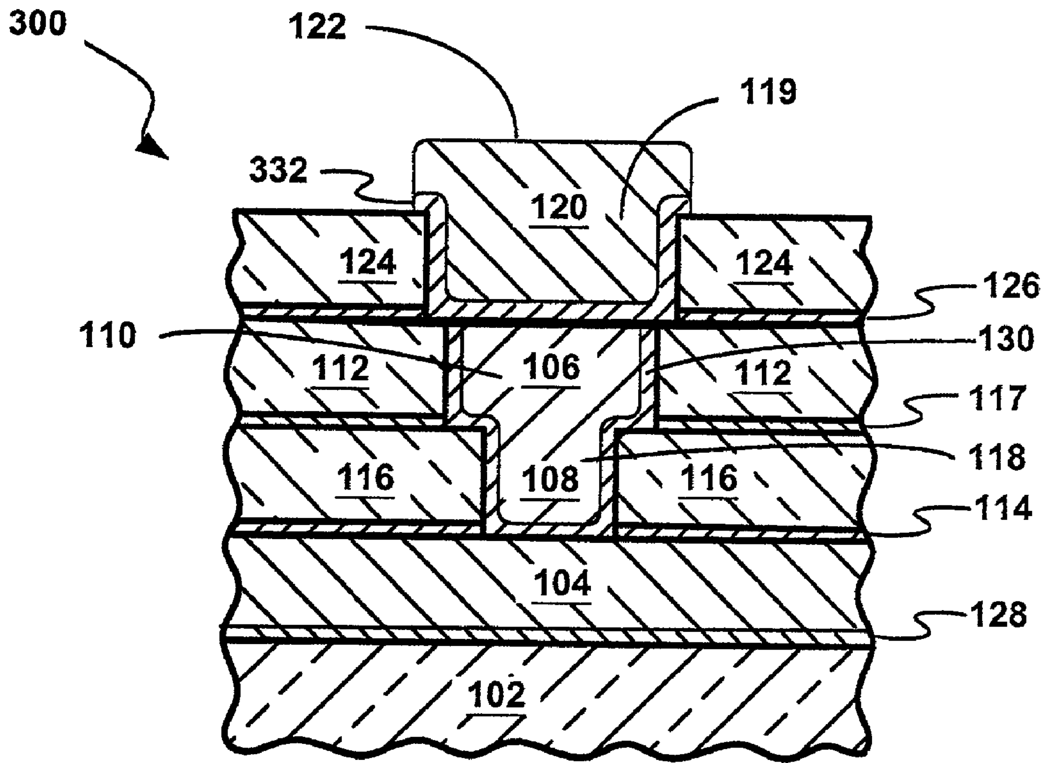


FIG. 3

PAD STRUCTURE FOR COPPER INTERCONNECTION AND ITS FORMATION

CROSS REFERENCE TO RELATED APPLICATION

[0001] This is a divisional of copending application Ser. No. 09/132,562 filed on Aug. 11, 1998.

TECHNICAL FIELD

[0002] The present invention relates generally to semiconductors and more specifically to barrier materials and pad structures used in semiconductor devices comprising high conductivity interconnection lines.

BACKGROUND ART

[0003] Conventional semiconductor devices typically are made up of a semiconductor substrate, normally a monocrystalline silicon with a plurality of dielectric and conductive layers formed thereon. An integrated circuit is formed of semiconductor devices connected by a plurality of spaced-apart conductive lines and a plurality of interconnection lines, such as bus lines, word lines and logic interconnection lines. Such interconnection lines generally constitute a limiting factor in terms of various functional characteristics of the integrated circuit. There exists a need to provide a reliable interconnection structure capable of achieving higher operating speeds, improved signal-to-noise ratio, improved wear characteristics, and improved reliability.

[0004] Most interconnection lines are made of aluminum or an aluminum-base alloy. The performance of a semiconductor device could be improved by forming the interconnection line of a metal having a higher conductivity than aluminum, thereby increasing current handling capability. It is known that copper, copper-base alloys, gold, gold-base alloys, silver and silver-base alloys generally exhibit a higher conductivity than aluminum and aluminum-base alloys, but each has its own drawbacks. One drawback of using copper, for example, is that copper readily diffuses through silicon dioxide, the typical dielectric material employed in the manufacture of semiconductor devices. Moreover, a low cost satisfactory method for etching copper has yet to be developed.

[0005] One method of forming copper interconnection lines is by using a "damascene" technique. Damascene is an art which has been employed for centuries in the fabrication of jewelry, and has recently been adapted for application in the semiconductor industry. Damascene basically involves the formation of a trench or a channel opening that is filled with a metal to form a channel. The traditional etch back technique of providing an interconnection structure involves depositing a metal layer, forming a conductive pattern with interwiring spacings, and filling the interwiring spacings with dielectric material. Thus, damascene differs from the traditional etch back technique by forming a pattern of openings in a dielectric layer, which openings are filled in with metal to form a conductive pattern followed by planarization.

[0006] In a "dual damascene" technique, two channels of conductive materials are positioned in vertically separate planes perpendicular to each other and interconnected by a vertical "via" at the closest point.

[0007] According to conventional practices, a plurality of conductive layers are formed over a semiconductor substrate, and the uppermost conductive layer joined to a bonding pad for forming an external electrical connection. In copper interconnection process, conductive layers would be formed by either damascene or dual damascene techniques. The uppermost conductive layer of the integrated circuit which is to be connected to the chip carrier is typically referred to as the wire bonding layer. The wire bonding layer has bonding pads which are used to make external connections by means of electrically conductive wires and external connection electrodes.

[0008] The most commonly used materials for the wire bonding layer are aluminum or aluminum-base alloys, such as aluminum with 2% copper. During the wire bonding process, the semiconductor device would be heated to above 200° C. A bonding tool coupled to a bonding machine would connect the bonding pads with external connection electrodes using electrically conductive wires. The electrically conductive wires are bonded to the bonding pads by the bonding tool using ultrasonic and thermal energies.

[0009] Copper or copper-base alloys are not used as wire bonding layers because copper or copper-base alloys tend to oxidize readily at temperature above 200° C. Once oxidized, the bonding pads would not be suitable for wire bonding. Therefore, even though the semiconductor industry is moving towards using copper as the material for interconnection lines, aluminum or aluminum-base alloys continue to be used as the materials for bonding pads.

[0010] A suitable conductive barrier layer is needed between the aluminum, or aluminum-base alloy, bonding pads and the underlying copper interconnection lines. Such a barrier layer can be conveniently formed by employing a material that is substantially impervious to the diffusion of aluminum atoms therethrough into the copper interconnection lines and to the diffusion of copper atoms therethrough into the aluminum or aluminum-base alloy bonding pads.

[0011] It is well known that titanium nitride (TiN) is a suitable conductive barrier material for aluminum, aluminum-base alloys, and copper. However, in copper interconnection processes, conventional tantalum nitride (TaN) is the most commonly used conductive barrier material. Besides TaN, tantalum silicon nitride (TaSiN) can also be used as a conductive barrier material for copper interconnection processes. The use of TiN would require additional deposition chambers because the deposition of TiN and TaN cannot be performed using the same deposition chamber. The need for additional deposition chambers for TiN deposition undesirably increases the cost and process complexity for the production of semiconductor devices.

[0012] Conventional TaN typically contains a nitrogen content by atomic weight of 20%. However, aluminum atoms from aluminum or aluminum-base alloys diffuse readily through conventional TaN, making it unsuitable for use as a conductive barrier layer between aluminum or aluminum-base alloys and copper interconnection lines. A method to form improved TaN layers that can be used as conductive barrier layers between aluminum or aluminum-base alloys and copper interconnection lines has long been sought but has eluded those skilled in the art.

DISCLOSURE OF THE INVENTION

[**0013**] The present invention provides tantalum nitride materials that are substantially impervious to the diffusion of aluminum atoms of an aluminum layer therethrough into an underlying conductive layer and the diffusion of atoms of the underlying conductive layer therethrough into the aluminum layer.

[**0014**] The present invention provides a method of manufacturing semiconductors having high conductivity interconnection lines, such as copper, by using a tantalum nitride material as a conductive barrier material between aluminum layers and the underlying high conductivity interconnection lines.

[**0015**] The present invention further provides a method of manufacturing semiconductors having high conductivity interconnection lines, such as copper, by using tantalum nitride materials which have high nitrogen content by atomic weight as a conductive barrier material between aluminum layers and the underlying high conductivity interconnection lines.

[**0016**] The present invention still further provides a method of forming tantalum nitride materials with high nitrogen content by increasing the nitrogen gas flow rate during the deposition of the tantalum nitride material.

[**0017**] The present invention also provides a semiconductor device having tantalum nitride materials with high nitrogen content by atomic weight as a conductive barrier material between aluminum layers and the underlying high conductivity interconnection lines formed of a material such as copper.

[**0018**] The above and additional advantages of the present invention will become apparent to those skilled in the art from a reading of the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0019**] **FIG. 1** (PRIOR ART) is a cross-section of semiconductor wafer with a pair of aligned semiconductor channels of conductive materials and a bonding pad disposed over a silicon substrate;

[**0020**] **FIG. 2** (PRIOR ART) is a physical vapor deposition chamber; and

[**0021**] **FIG. 3** is a cross-section of semiconductor wafer with a pair of aligned semiconductor channels of a conductive material and a bonding pad disposed over a silicon substrate manufactured in accordance with the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[**0022**] Referring now to **FIG. 1** (PRIOR ART), therein is shown a cross-section of semiconductor wafer **100** with a pair of aligned semiconductor channels of a conductive material, such as copper, disposed over a silicon substrate **102**. A first channel **104** is shown disposed below a second channel **106** which extends substantially perpendicular to the first channel **104**. Similarly, a via **108** connects the first and second channels **104** and **106**, which is a part of the second channel **106**. The first channel **104** comprises a first conductive material. The second channel **106** is formed by filling a second channel opening **110** disposed in a second channel oxide layer **112** with a second conductive material.

[**0023**] The first and second channels **104** and **106** are in horizontal planes separated vertically by a first stop nitride layer **114**, a via oxide layer **116**, and a thin via nitride layer **117**. The cylindrical via opening **118** forms the cylindrical via **108** when it is filled with the second conductive material.

[**0024**] A wire bonding layer **120**, typically an aluminum or aluminum-base alloy, is the uppermost conductive layer and is shown disposed over the second channel **106**. The wire bonding layer **120** comprises aluminum or aluminum-base alloys.

[**0025**] The second channel **106** and the wire bonding layer **120** are in horizontal planes separated vertically by a second stop nitride layer **126** and an oxide layer **124**.

[**0026**] Also shown disposed around the first channel **104** is barrier material **128**, around the second channel **106** and the cylindrical via **108** is barrier material **130**, and around the wire bonding layer **120** is barrier material **132**. Barrier materials, where necessary, are used to prevent electromigration or diffusion of the conductive materials into the adjacent areas of the semiconductor. Tantalum nitride is the most commonly used barrier material for copper channels. Accordingly, barrier material **128** and **130** would be tantalum nitride. In the prior art, since the wire bonding layer comprises aluminum or aluminum-base alloys, the barrier material would be titanium nitride since conventional tantalum nitride is not a suitable barrier material for aluminum or aluminum-base alloys.

[**0027**] Referring now to **FIG. 2** (PRIOR ART), therein is shown a physical vapor deposition chamber **200**. Chamber **200** can be used to deposit or sputter metal films, such as conductive barrier materials, onto the surface of a silicon substrate **202**. Substrate **202** is disposed over a substrate holder **204** and is positioned face-up in the chamber **200**. A target **206** is shown positioned face-down within the chamber **200**. The target **206** is made of the material that is to be deposited onto the silicon substrate **202**. A shield **208** is positioned within the interior of the chamber **200** to prevent target material from being deposited on the interior walls **209** of the chamber **200**. Chamber **200** also includes inlets (not shown) for receiving gases such as argon and nitrogen that are to be used during the deposition of metal films. A direct current (DC) voltage source **210** is coupled between the target **206** (cathode), and the shields **208** (anode) for generating a plasma using argon gas. By applying a negative voltage to the target **206**, the ions in the plasma will be attracted to the target **206** as the plasma is formed. As the plasma ions strike the target **206**, particles are sputtered from the surface of the target **206** at a significant kinetic energy. The sputtered particles from target **206** are then deposited onto the silicon substrate **202** in the form of a thin metal film.

[**0028**] Chamber **200** can be used to conduct reactive sputtering using more than one element to make up the deposition material. In a reactive sputtering process, nitrogen gas would be introduced into the chamber **200** during the deposition. As a result, the sputter surface of the target **206** is in a nitrided-mode. For example, when TaN is to be deposited onto the silicon substrate **202**, the target **206** would be formed of tantalum. In the nitrided-mode, the

nitrogen gas would cause tantalum nitride to be deposited. Similarly, when TaSiN is to be deposited onto the silicon substrate **202**, the target **206** would be formed of tantalum silicon. In the nitrided-mode, the nitrogen gas would cause tantalum silicon nitride to be deposited. The nitrided compound, e.g., TaN or TaSiN, would be deposited onto the silicon substrate **202** during the physical vapor deposition.

[**0029**] As explained in the Background Art, copper or copper-base alloys are not used as wire bonding layer because copper or copper-base alloys tend to oxidize readily at the wire bonding temperature which is above 200° C. Once oxidized, the bonding pads would not be suitable for wire bonding because the oxide acts as an insulator. Therefore, aluminum or aluminum-base alloys continue to be used as the materials for bonding pads even in the copper interconnection processes.

[**0030**] In the copper interconnection processes, conventional tantalum nitride (TaN) is the most commonly used conductive barrier. However, aluminum atoms from aluminum or aluminum-base alloys diffuse readily through conventional TaN, making it unsuitable for use as a conductive barrier layer between aluminum or aluminum-base alloys bonding pads and copper interconnection lines.

[**0031**] Although titanium nitride (TiN) is a suitable conductive barrier for aluminum, aluminum-base alloys and copper, the use of TiN as a conductive barrier would require additional deposition chambers because the deposition of TiN and TaN cannot be performed using the same deposition chamber. The need for additional deposition chambers for TiN deposition undesirably increases the cost and process complexity for the production of the semiconductor devices.

[**0032**] The present invention provides a method for forming improved tantalum nitride material layers that can be used as conductive barrier layers between aluminum or aluminum-base alloys and high conductivity connection lines formed of material such as copper.

[**0033**] Referring to **FIG. 3**, therein is shown the cross-section of a semiconductor wafer **300** with a pair of aligned semiconductor channels of a conductive material, such as copper, disposed over a silicon substrate **102** formed in accordance with the present invention. For convenience of illustration, like reference numerals are used in **FIG. 3** to denote like elements already described in **FIG. 1**. **FIG. 3** is identical to **FIG. 1** except that in this preferred embodiment, barrier material **332** is formed of tantalum nitride material such as TaN_2, a combination of TaN and TaN_2, $TaSiN_2$, a combination of TaSiN and $TaSiN_2$, or a combination of the aforegoing with a nitrogen content by atomic weight of between 20% and 40%. Unlike the conventional tantalum nitride which comprises a nitrogen content by atomic weight of about 20%, the material formed according to the present invention contains a nitrogen content by atomic weight of more than about 30% and less than about 40%. The tantalum nitride material formed is substantially impervious to the diffusion of aluminum atoms therethrough into the second copper channel **106** and the diffusion of copper atoms therethrough into the aluminum bonding pad **122**. Therefore, the tantalum nitride material is suitable to be used as a barrier material between the bonding pad **122** and copper channel **106**. As described earlier, barrier materials **128** and **130** also comprise TaN since TaN would be used for copper interconnection lines. Accordingly, with the present invention, the same deposition chamber can be used for forming barrier material **128**, **130**, and **232** and no additional TiN deposition chamber is required.

[**0034**] In production, a conventional first damascene process was used to put down over a production semiconductor wafer **300** a first channel **104** in a first channel oxide layer (not shown) above portions of a semiconductor device which is formed over a silicon substrate **102**. The damascene process is a photolithographic process which uses a mask to define a first channel opening (not shown) in the first channel oxide layer to run in a first direction (which is horizontal in **FIG. 1**). The first channel opening is then filled with a first conductive material, such as copper, to form the first channel **104** using conventional metal deposition technique, such as physical vapor deposition, chemical vapor deposition, electroplating, or a combination thereof. The stop nitride layer **114**, the via oxide layer **116**, and the via nitride layer **117** would be successively deposited on top of the first channel **104** and the first channel oxide layer using conventional deposition technique.

[**0035**] By using the via photoresist and the via photolithographic process followed by nitride etching of a round via opening **118** in the via nitride layer **117**, the basis for the cylindrical via **108** was formed. The subsequent deposition of the second channel oxide layer **112** prepared the way for the second channel **106** to be perpendicular to the first channel **104**. The second damascene process is a photolithographic process which uses a mask to define the second channel opening **110** in the second channel oxide layer **112**. Since the second damascene process uses an anisotropic oxide etch, the etch also forms the cylindrical via opening **118** down to the stop nitride layer **114**. The anisotropic oxide etch etches faster in the vertical direction of **FIG. 1** than in the horizontal direction. The nitride etch of the stop nitride layer **114** completes the etching steps. The deposition of the barrier material **130**, such as a conventional TaN and the second conductive material, such as copper, into second channel opening **110** and via opening **118** forms the second channel **106** and the cylindrical via **108**. The barrier material **130** is deposited using conventional deposition techniques, such as physical vapor deposition, chemical vapor deposition, or a combination thereof. Similarly, the second conductive material is deposited using conventional metal deposition technique, such as physical vapor deposition, chemical vapor deposition, electroplating, or a combination thereof. Thereafter, a chemical mechanical polishing process is used to complete the conventional connection process.

[**0036**] Thereafter, a second stop nitride layer **126** and the wire bonding oxide layer **124** would be successively deposited over the second channel **106** and the second channel oxide layer **112** using conventional deposition techniques. By using a conventional photolithographic and etching process, a bonding pad opening **119** would be formed in the wire bonding oxide layer **124** and over second channel **106**.

[**0037**] Next, the barrier material **332** is deposited over the sidewalls and the bottom of the bonding pad opening **119** in accordance with the present invention. In a preferred embodiment, the barrier material **332** is the tantalum nitride material. It can be deposited using the deposition chamber **200**. Chamber **200** would be pumped down to a vacuum in the milli-Torr (mTorr) range after the semiconductor wafer **300** has been positioned over the substrate support **204**.

Argon and nitrogen gases are then introduced into the chamber **200**. A high DC voltage is applied across the target **206** and the shield **208** using DC voltage source **210** to generate a plasma. The nitrogen converts the target **206** into a nitrided-mode so that reactive sputtering can take place which results in the deposition of a layer of TaN_2 or the combination of TaN_2 and TaN over the sidewalls and the bottom of the bonding pad opening **119**. In the best mode, the flow rate of the nitrogen gas would be within the range of about 28 to about 40 sccm (standard cubic centimeters), while the flow rate of the argon gas would be about 45 sccm. The deposition pressure would be within the range of about 5 mTorr to about 20 mTorr, and preferably about 8 mTorr. The DC power supplied by the DC voltage source **210** would be within the range of about 0.5 kW to about 4 kW, and preferably about 2 kW.

[**0038**] To deposit TaN_2 or the combination of TaN_2 and TaN, it is important to maintain a high nitrogen flow rate relative to the argon flow rate. Specifically, TaN_2 or the combination of TaN_2 and TaN will be formed when the ratio of the nitrogen flow rate and the argon flow rate is within the range of about 28/45 to about 40/45. Further, the DC power should not be more than about 4 kW because higher DC power tends to reduce the amount of nitrogen incorporation into the resulting tantalum nitride material, making it unsuitable to act as a conductive barrier between aluminum or aluminum-base alloys and copper.

[**0039**] It has also been determined that a conductive barrier of 50 angstroms thickness will perform the barrier function satisfactorily. However, due to current bonding impacts which cause physical damage to the conductive barrier, thicknesses of between 400 to 500 angstroms are currently preferred.

[**0040**] After the deposition of barrier material **332** in the bonding pad opening **119**, the bonding pad opening **119** is filled with aluminum or aluminum-base alloys followed by a conventional photolithographic and etching process to form the wire bonding layer **120** which comprises a bonding pad **122**.

[**0041**] Accordingly, with the present invention, the improved tantalum nitride material can be formed which functions as a conductive barrier material between aluminum or aluminum-base alloys and copper. Therefore, the same deposition chamber can be used for forming barrier material layers for copper interconnection lines without the need for additional TiN deposition chambers.

[**0042**] While the best mode utilizes copper as the conductive material, it should be understood that the present invention is applicable to other high conductivity materials such as copper-base alloys, gold, gold-base alloys, silver, and silver-base alloys. Further, the present invention is also applicable to provide a layer of $TaSiN_2$ or a combination of $TaSiN_2$ and TaSiN that can be used as conductive barrier materials between aluminum or aluminum-base alloys and copper.

[**0043**] As would be evident to those skilled in the art, besides physical vapor deposition, other deposition techniques, such as chemical vapor deposition, could be used to deposit the tantalum nitride material that can be used as conductive barrier materials between aluminum or aluminum-base alloys and high conductivity materials such as copper.

[**0044**] While the invention has been described in conjunction with a specific best mode, it is to be understood that many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the aforegoing description. Accordingly, it is intended to embrace all such alternatives, modifications, and variations which fall within the spirit and scope of the included claims. All matters set forth herein or shown in the accompanying drawings are to be interpreted in an illustrative and non-limiting sense.

The invention claimed is:

1. A semiconductor device, comprising:

a semiconductor substrate;

a conductive layer formed on said semiconductor substrate;

a conductive barrier layer formed on said conductive layer wherein said conductive barrier layer is a tantalum nitride material selected from the group consisting of TaN_2, $TaSiN_2$, the combination of TaSiN and $TaSiN_2$, and the combination of TaN_2, TaSiN and $TaSiN_2$; and

an aluminum layer formed on said conductive barrier layer wherein said conductive barrier layer is substantially impervious to the diffusion of aluminum atoms therethrough into said conductive layer and the diffusion of atoms of said conductive layer therethrough into said aluminum layer.

2. The semiconductor device according to claim 1, wherein said conductive layer is a metal selected from the group consisting of copper, copper-based alloys, gold, gold-based alloys, silver, and silver-based alloys.

3. The semiconductor device according to claim 1, wherein said conductive barrier layer has a thickness within the range of about 50 to about 2,000 angstroms.

4. A semiconductor device, comprising:

a semiconductor substrate;

a conductive layer formed on said semiconductor substrate;

a conductive barrier layer formed on said conductive layer wherein said conductive barrier layer is a tantalum nitride material selected from the group consisting of TaN_2 and $TaSiN_2$; and

an aluminum layer formed on said conductive barrier layer wherein said conductive barrier layer is substantially impervious to the diffusion of aluminum atoms therethrough into said conductive layer and the diffusion of atoms of said conductive layer therethrough into said aluminum layer.

5. The semiconductor device according to claim 4, wherein said tantalum nitride material contains a nitrogen content by atomic weight of more than about 30%.

6. The semiconductor device according to claim 4, wherein said tantalum nitride material contains a nitrogen content by atomic weight of less than about 40%.

7. The semiconductor device according to claim 4, wherein said aluminum layer constitutes a wire bonding layer for external connection thereto.

8. The semiconductor device according to claim 4, wherein said conductive layer is in electrical and physical contact with said conductive barrier layer, and said first conductive barrier layer is in electrical and physical contact with said aluminum layer.

9. A semiconductor device, comprising:

a semiconductor substrate;

a conductive layer formed on said semiconductor substrate, wherein said conductive layer is a metal selected from the group consisting of copper, copper-based alloys, gold, gold-based alloys, silver, and silver-based alloys;

a conductive barrier layer formed on said conductive layer wherein said conductive barrier layer is a tantalum nitride material selected from the group consisting of TaN_2, $TaSiN_2$, the combination of TaN_2 and $TaSiN_2$, the combination of TaSiN and $TaSiN_2$, and the combination of TaN_2, TaSiN and $TaSiN_2$; and

an aluminum layer formed on said conductive barrier layer; wherein said conductive barrier layer is substantially impervious to the diffusion of aluminum atoms therethrough into said conductive layer and the diffusion of atoms of said conductive layer therethrough into said aluminum layer.

10. The semiconductor device according to claim 9, wherein said conductive barrier layer has a thickness greater than 50 angstroms.

11. The semiconductor device according to claim 9, wherein said tantalum nitride material contains a nitrogen content by atomic weight of more than about 30%.

12. The semiconductor device according to claim 9, wherein said tantalum nitride material contains a nitrogen content by atomic weight of less than about 40%.

13. The semiconductor device according to claim 9, wherein said aluminum layer constitutes a wire bonding layer for external connection thereto.

14. The semiconductor device according to claim 9, wherein said conductive layer is in electrical and physical contact with said conductive barrier layer, and said first conductive barrier layer is in electrical and physical contact with said aluminum layer.

15. A semiconductor device, comprising:

a semiconductor substrate;

a conductive layer formed on said semiconductor substrate, wherein said conductive layer is a metal selected from the group consisting of copper, copper-based alloys, gold, gold-based alloys, silver, and silver-based alloys;

a conductive barrier layer formed on said conductive layer wherein said conductive barrier layer is a tantalum nitride material selected from the group consisting of TaN_2, $TaSiN_2$, the combination of TaN_2 and $TaSiN_2$, the combination of TaSiN and $TaSiN_2$, and the combination of TaN_2, TaSiN and $TaSiN_2$, and has a thickness within the range of about 50 to about 2,000 angstroms; and

an aluminum layer formed on said conductive barrier layer wherein said aluminum layer constitutes a wire bonding layer for external connection thereto, said conductive layer is in electrical and physical contact with said conductive barrier layer, and said first conductive barrier layer is in electrical and physical contact with said aluminum layer, and said conductive barrier layer is substantially impervious to the diffusion of aluminum atoms therethrough into said conductive layer and the diffusion of atoms of said conductive layer therethrough into said aluminum layer.

16. The semiconductor device according to claim 15, wherein said conductive barrier layer contains a nitrogen content by atomic weight of more than about 30% and less than about 40%.

* * * * *